



# Functional Diversity at Landscape Scale using Sentinel-2 imagery

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# Measuring functional diversity using remote sensing

- Functional diversity
  - Measuring diversity using functional traits
  - Morphological, physiological and phenological traits
  - Derived from remotely sensed data

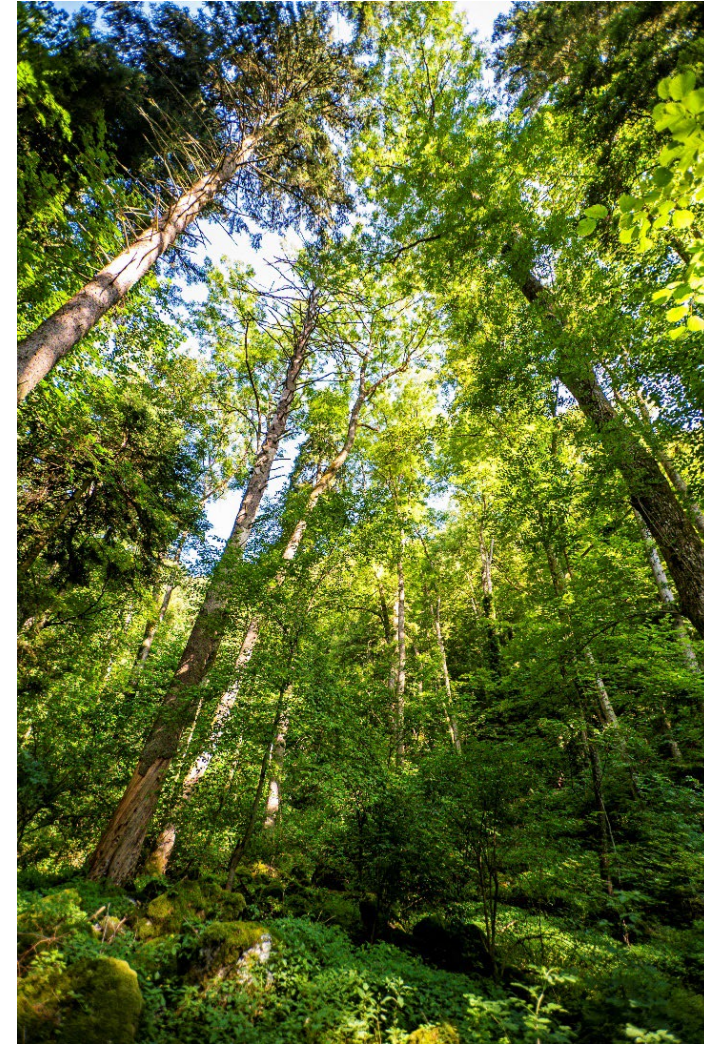
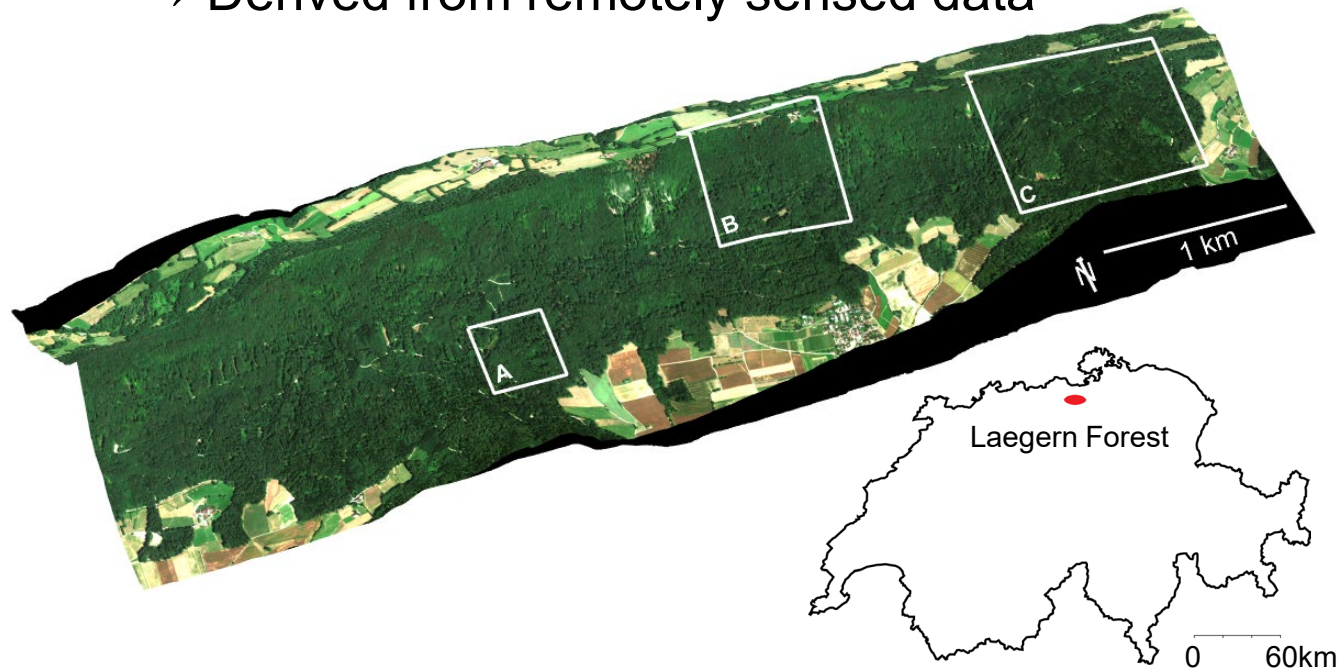
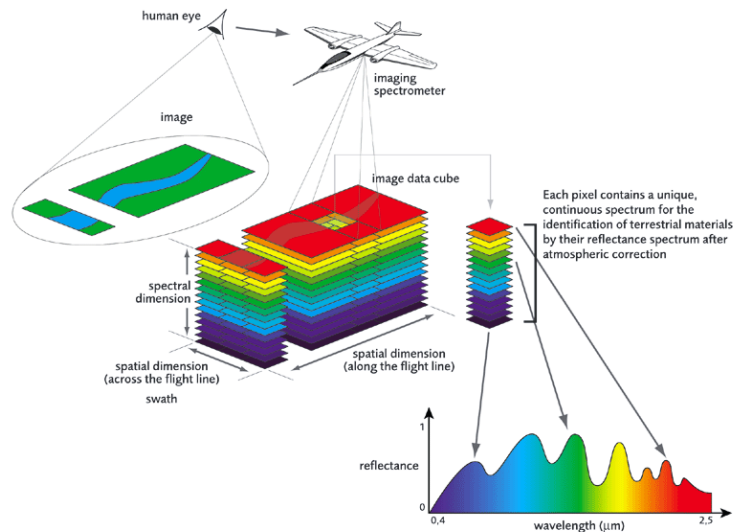


Image: F. D. Schneider

# Airborne and spaceborne systems

- 1. Introduction
- 2. Methods
- 3. Results
- 4. Conclusion

Sensor	Airborne Prism Experiment APEX	ESA's Sentinel-2A and 2B
Temporal resolution	2 – 6 campaigns per year	repeat cycle: 10 days with one satellite and 5 days with 2 satellites
Spatial resolution	2 m pixel size	10 m, 20 m and 60 m pixel size
Spectral resolution	284 spectral bands	13 spectral bands



ESA (2017) "Sentinel-2 MSI". Available at: <https://earth.esa.int/web/sentinel/user-guides/sentinel-2-msi> (Accessed: 21 May 2017).

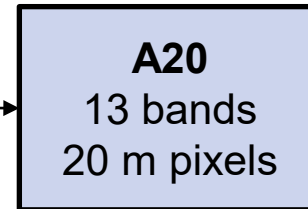
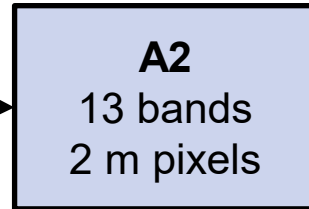
Schaepman, M. E. et al. (2015) "Advanced radiometry measurements and Earth science applications with the Airborne Prism Experiment (APEX)", *Remote Sensing of Environment*, 158, pp. 207–219. DOI: 10.1016/j.rse.2014.11.014.

Images: <http://www.apex-esa.org/content/imaging-spectroscopy/>, [https://de.wikipedia.org/wiki/Sentinel-2#/media/File:Sentinel\\_2-IMG\\_5873-white.jpg](https://de.wikipedia.org/wiki/Sentinel-2#/media/File:Sentinel_2-IMG_5873-white.jpg)

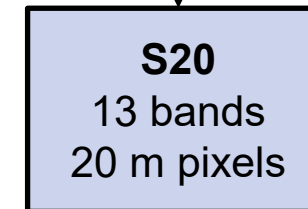
# Scaling functional diversity to Sentinel-2

## APEX data preprocessing

APEX data  
 284 bands  
 2 m pixels

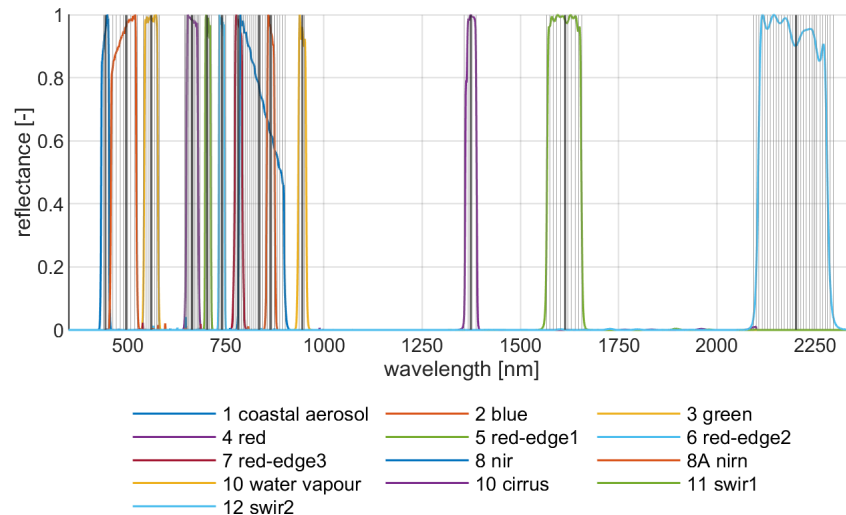


## Sentinel-2 data preprocessing

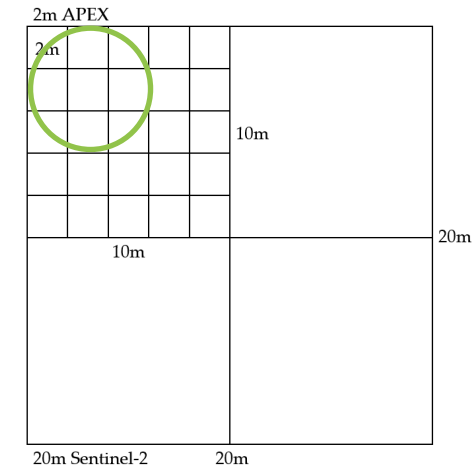


1. Spectral convolution 2. Spatial resampling

## Spectral Resolution



## Spatial Resolution





# Spectral indices as proxies for physiological traits

- 18 spectral indices as proxies for **chlorophyll content**, **canopy water content**, **red pigments** (anthocyanin content, carotenoid content, carotenoid/chlorophyll ratio)

Conditions:

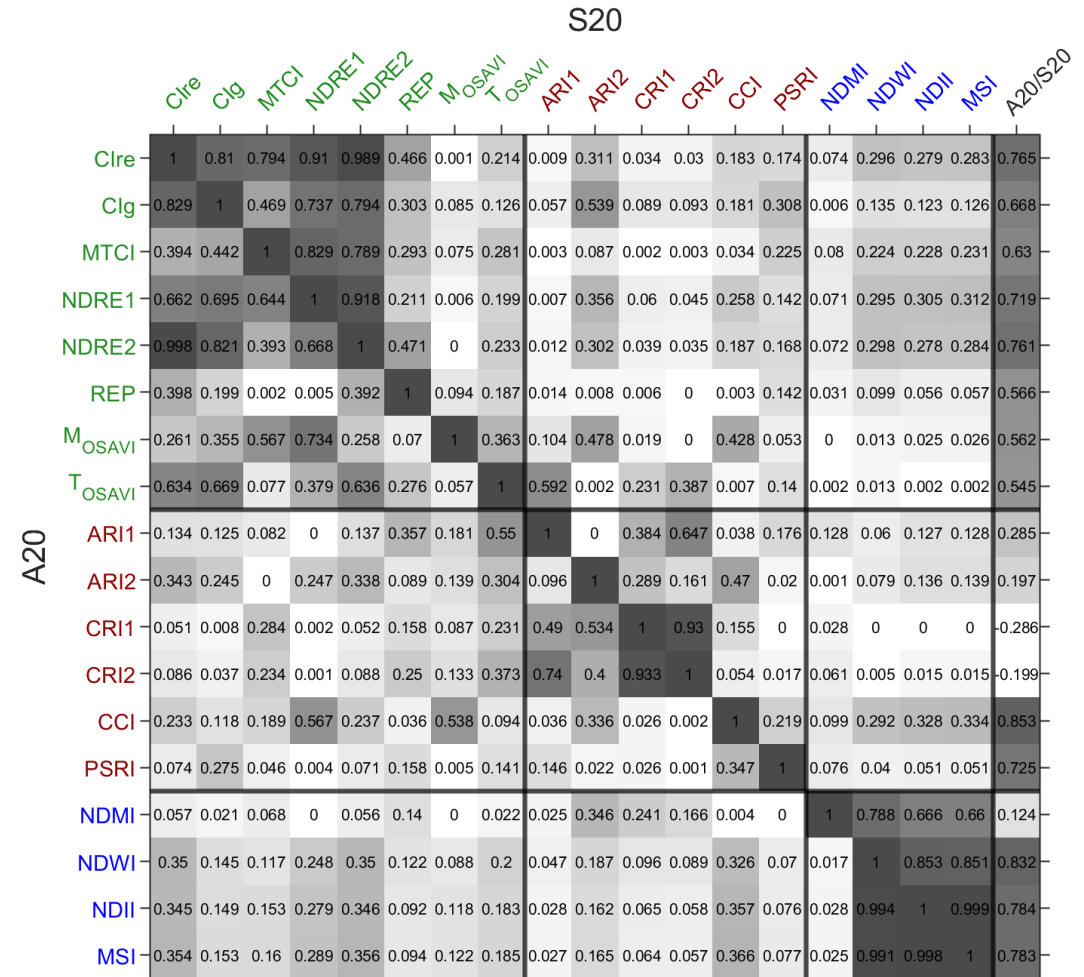
- supported by the spectral resolution of the Sentinel-2 MSI sensor
- high correlation when linked to the same trait, but not between traits
- high correlation between datasets A20 and S20
- suitable at different spatial scales

Results:

**Chlorophyll:** Clre, NDRE2, Cig

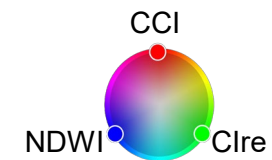
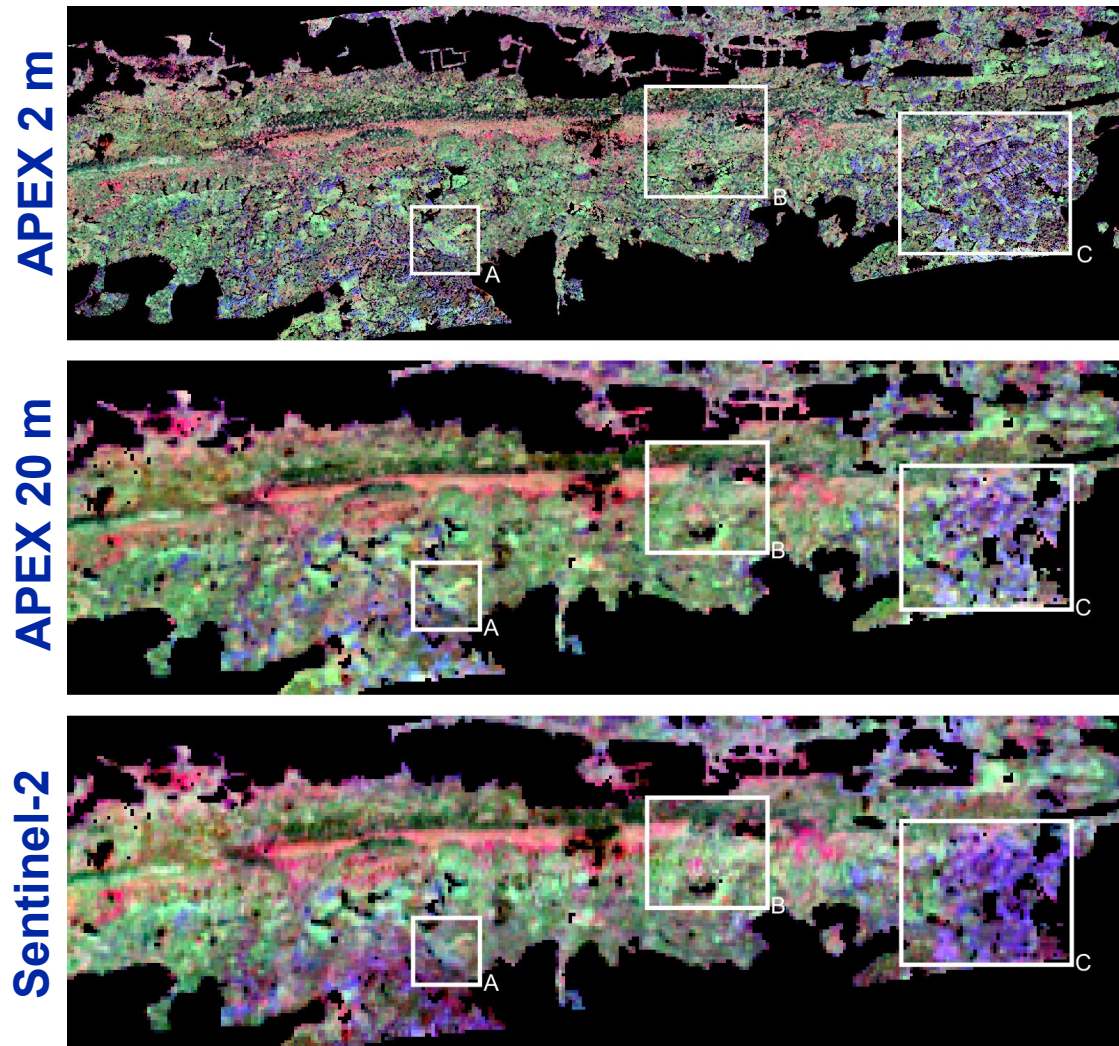
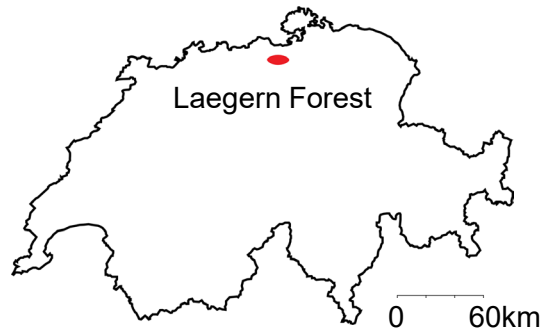
**Red pigments:** CCI, PSRI

**Water content:** NDWI, NDII



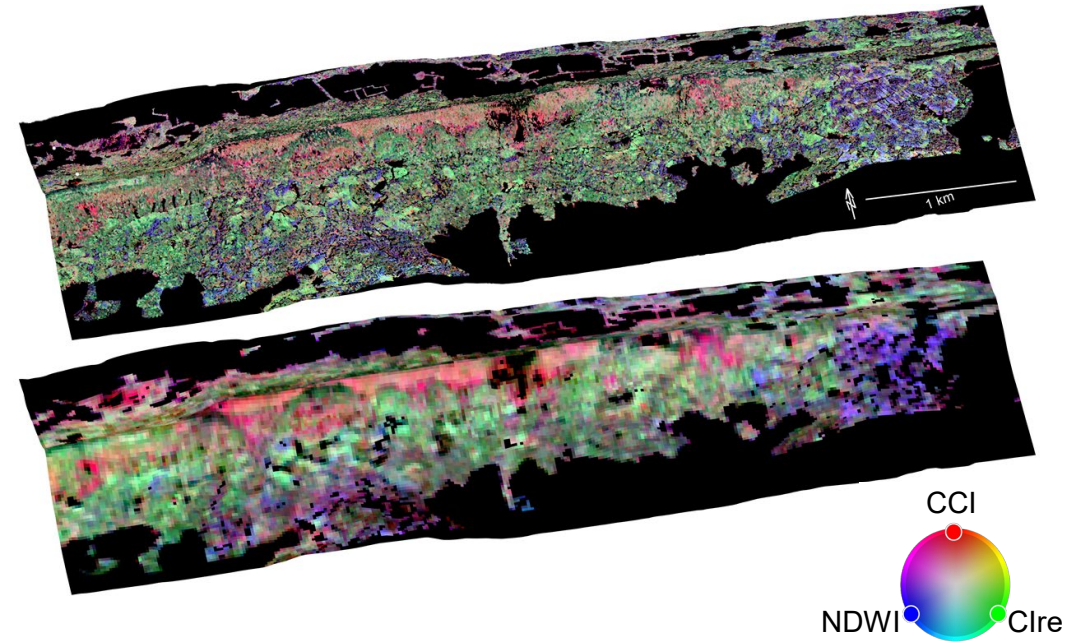
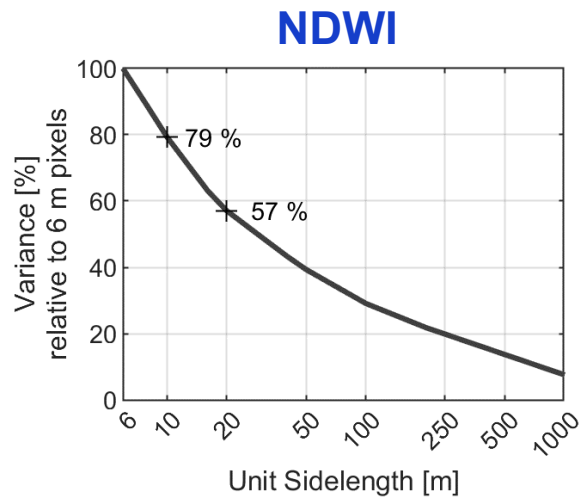
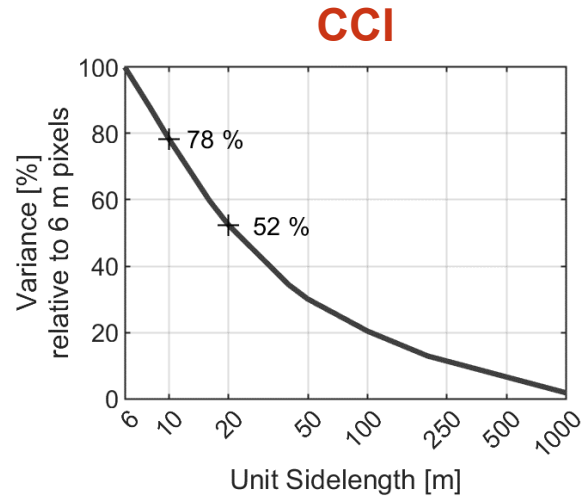
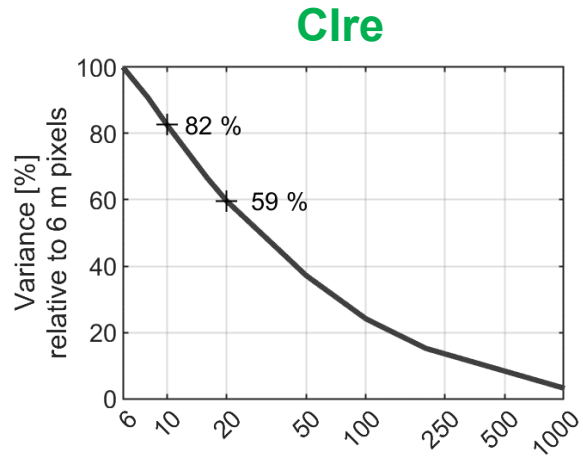
# Physiological trait maps

- 1. Introduction
- 2. Methods
- 3. Results
- 4. Conclusion



# Impact of spatial resolution on variance of physiological traits

- 1. Introduction
- 2. Methods
- 3. Results
- 4. Conclusion

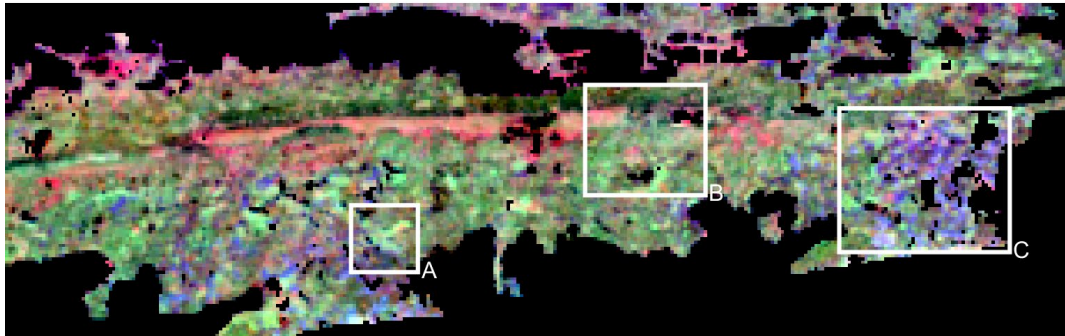




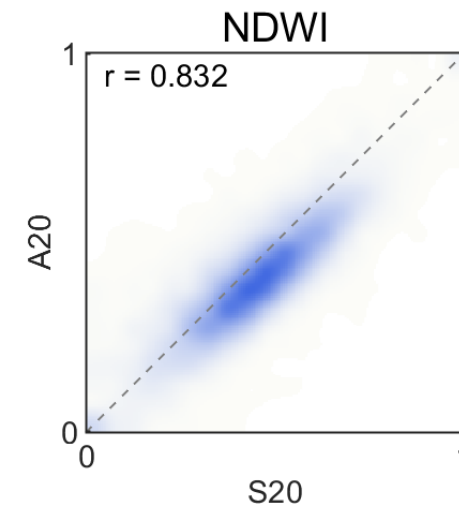
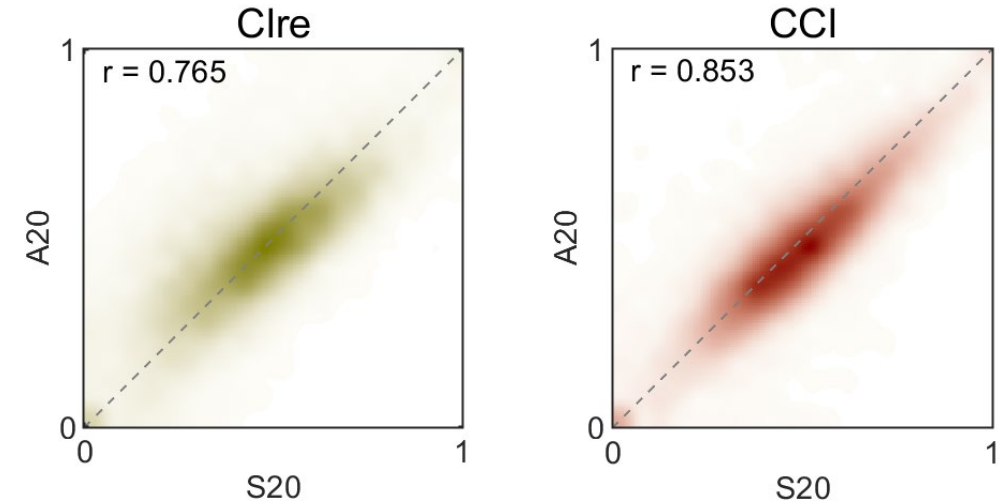
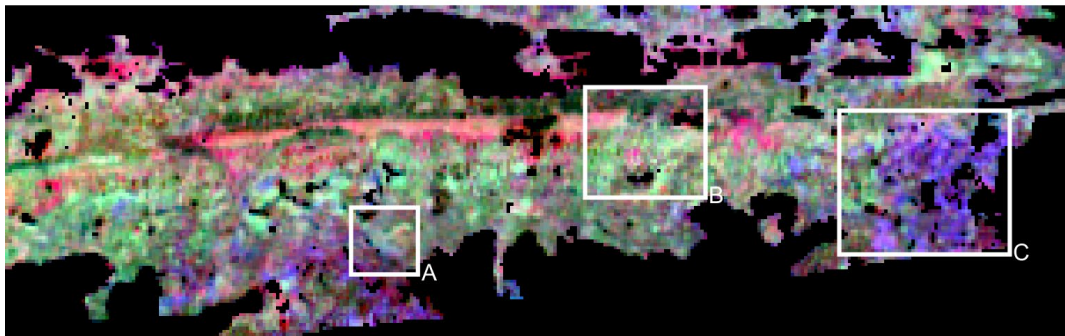
# Impact of sensors on physiological traits

- 1. Introduction
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APEX 20 m



Sentinel-2





# Measuring functional diversity using Remote Sensing

Vegetation indices

Physiological traits

Clre

Chlorophyll

CCI

Carotenoid/  
Chlorophyll  
ratio

NDWI

Water

Physiological trait space  
(varying neighborhood area / number of points)

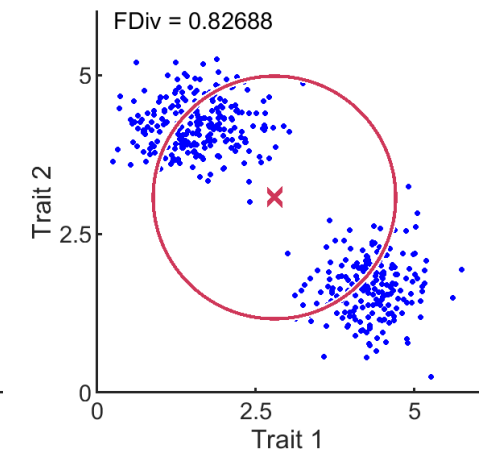
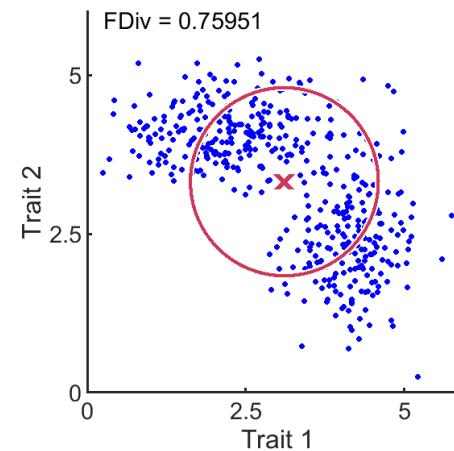
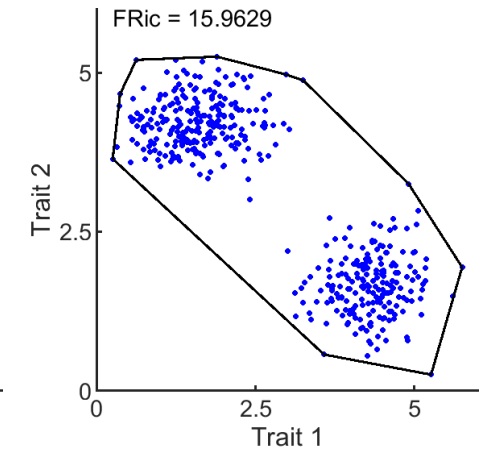
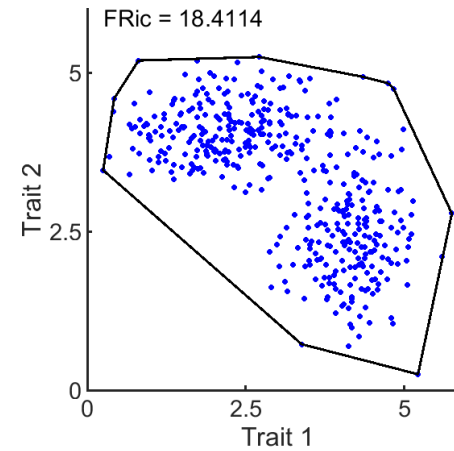
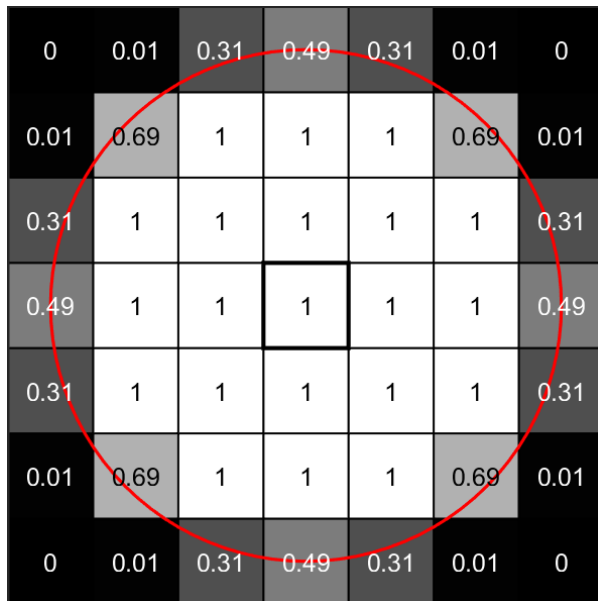
Functional diversity metrics

Physiological  
Richness

Physiological  
Divergence

# Functional diversity metrics

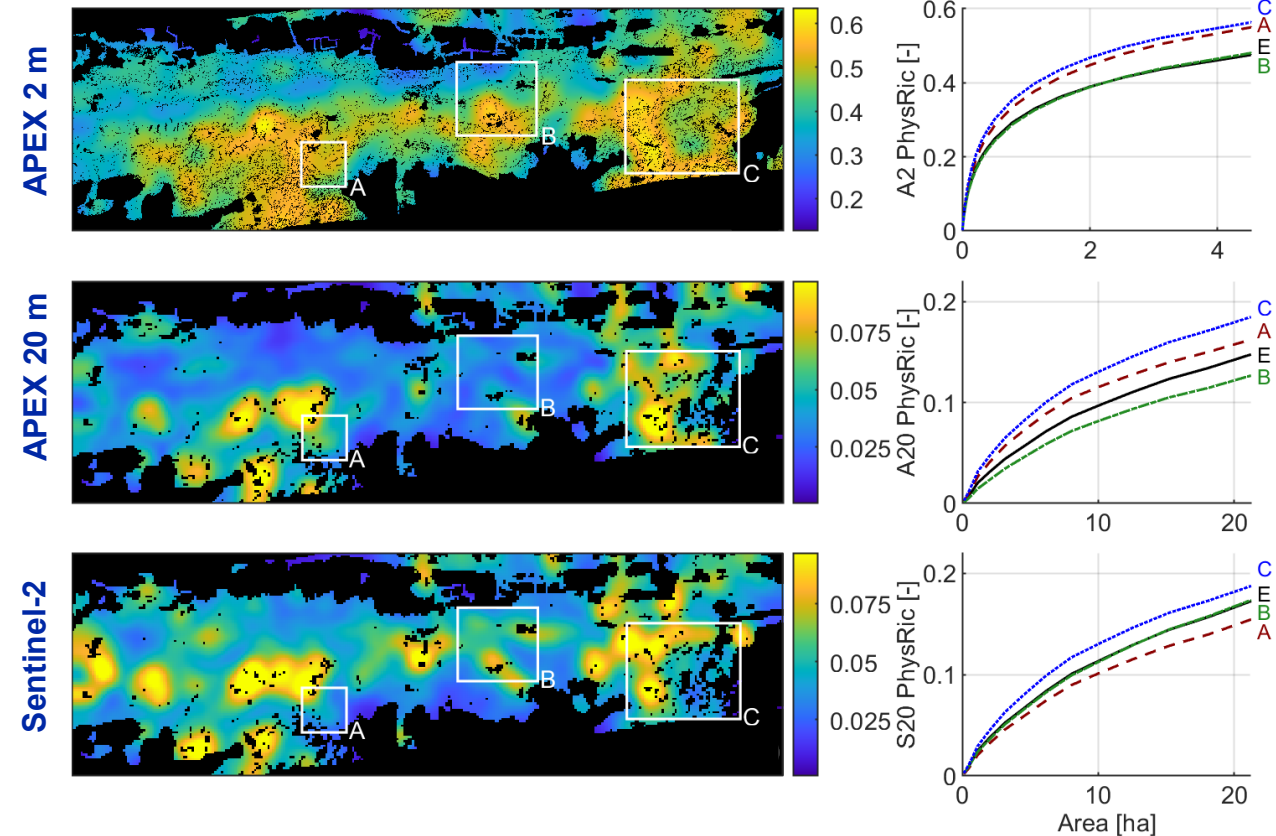
- Functional Richness  
= measure of extent  
→ How many different value are present?
- Functional Divergence  
= measure of distribution  
→ How are the different values organized?



# Physiological diversity maps

- New value range
- Interpretation of large scale patterns
- Interpretations of results: increase around 'hotspots'
- Mixed-pixels around forest edge and gaps  
→ Increase in functional richness
- Richness-area relationships change with pixel size

## Physiological Richness

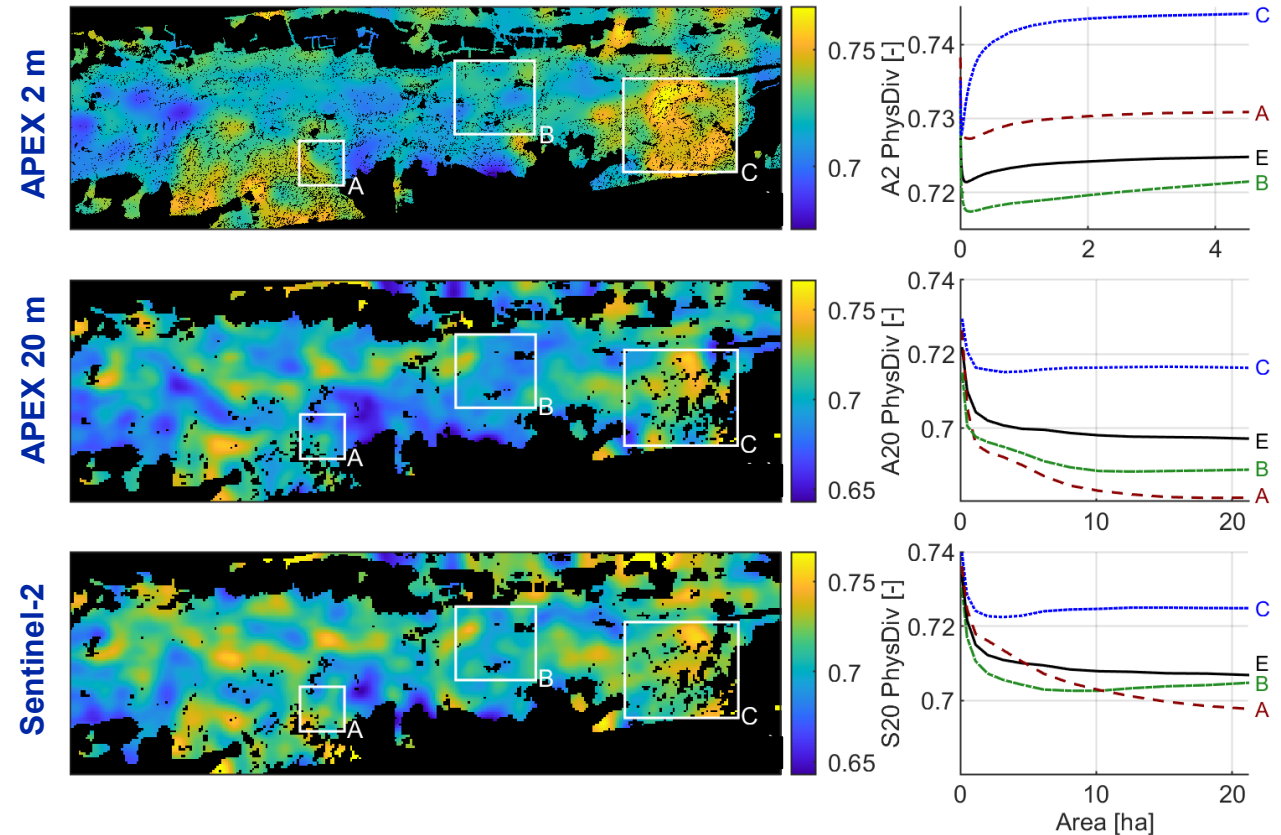




# Physiological diversity maps

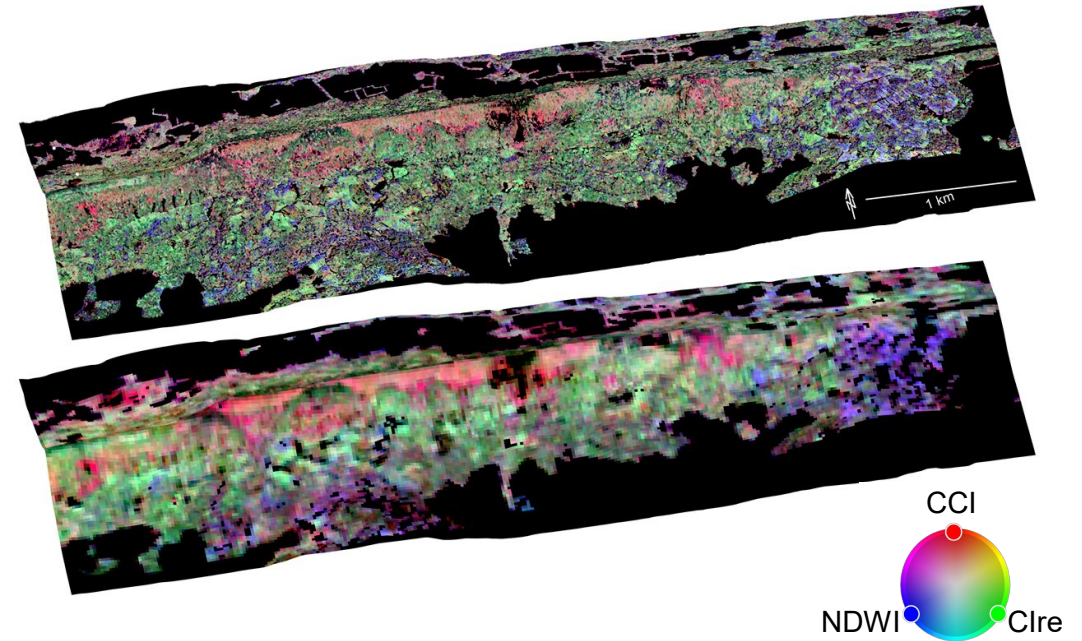
- Values comparable through scale
- Interpretation of large scale patterns: increase of functional divergence at transition of communities
- Mixed-pixels around forest and gaps
  - Decrease in functional divergence
- Stabilization of divergence at  $> 3$  pixel radius
  - Minimum calculation area

## Physiological Divergence



# Functional Diversity using Sentinel-2 imagery

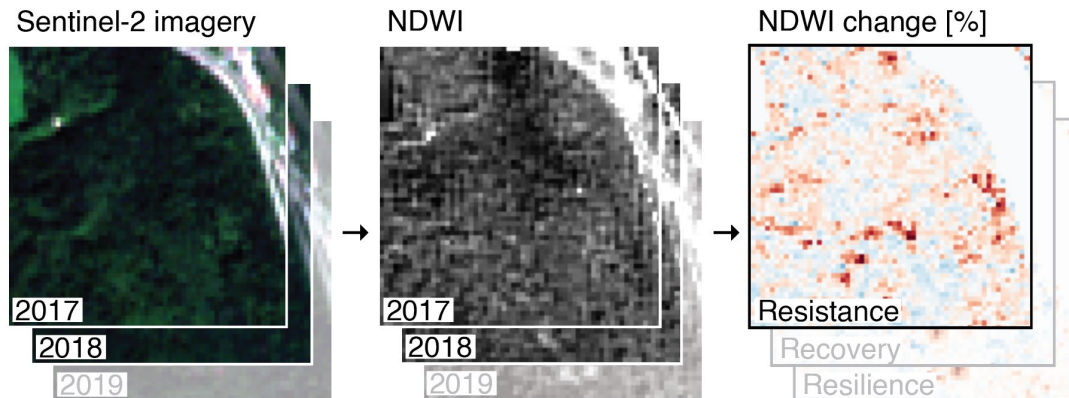
- Observing functional diversity continuously in time and space using satellite imagery
- Functional diversity metrics depend on the size and number of pixels
- Minimum calculation area with 60 m radius or 1.1 ha recommended
- Importance of spatial and spectral resolution when scaling diversity assessments to landscape scales
- Promising applications at landscape scales





## A2.03 Ecosystem Resilience

# Topography and stand characteristics controlled forest response to the 2018 drought in Switzerland

Sturm, J., Santos, M.J., Schmid, B., Damm, A.



### Site specific characteristics determine drought resistance of Swiss forests

Joan Sturm<sup>1\*</sup>, Maria J. Santos<sup>1</sup>, Bernhard Schmid<sup>1</sup>, and Alexander Damm<sup>2</sup>  
\*Contact: joantracy.sturm@geo.uzh.ch

#### Introduction

- Intensified frequency of extreme events.
- Changes to both the global water and carbon cycles influence forest ecosystems.
- 2018 was one of the driest and hottest summers in Switzerland (Fig. 1).
- Reduced leaf water content, leaf discoloration, and tree mortality were observed.
- Naturally occurring sequence of pre-drought, drought, and post-drought conditions.

How do gradients of environmental variables affect forest drought response?

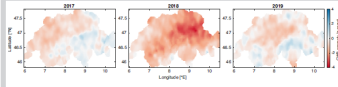


Fig. 1. Climatic water balance (CWB) anomalies for the integrated periods of March to August 2017, 2018, and 2019 relative to the norm of 1981–2010 (data source: MeteoSwiss).

#### Data & Methods

We analysed Sentinel-2 bottom of atmosphere reflectance imagery from August 2017, 2018, and 2019 at a 10x10 m spatial resolution. The normalised difference water index (NDWI) [1] was taken as a proxy for drought effects on forests. The NDWI is sensitive to leaf water content, an early response to drought conditions, and is stable over Switzerland's challenging topography.

We used simple linear mixed models to assess the relationship between percentage affected forest pixels and environmental variables such as climate drivers, topographic modifiers, and forest stand characteristics (e.g. Fig. 2).

The slope of the regression line, indicating the direction of the correlation, was then used to define the angle of the arrow in Fig. 3. The cells were coloured according to their R<sup>2</sup> value which expresses the goodness-of-fit of the linear model.

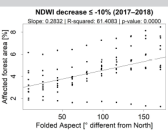


Fig. 2. Scatterplot for the relation between the site characteristic Fitted Aspect (° different from North) and the proportion of forest area with a NDWI change <math>\leq -10\%</math> from 2017–2018.

#### Results

	NDWI change <math>\leq -10\%</math>			NDWI change <math>\geq 10\%</math>		
	2017	2018	2019	2017	2018	2019
<b>Climate</b>						
Temperature anomaly to norm (increase)	↘	↘	↘	↘	↘	↘
Precipitation anomaly to norm (decrease)	↘	↘	↘	↘	↘	↘
CWB anomaly (z-score) (decrease)	↘	↘	↘	↘	↘	↘
<b>Topography</b>						
Elevation (increase)	↘	↘	↘	↘	↘	↘
Slope (increased steepness)	↘	↘	↘	↘	↘	↘
Folded aspect (southerly)	↘	↘	↘	↘	↘	↘
Potential direct incident radiation (increase)	↘	↘	↘	↘	↘	↘
Topographic position index (increased exposition)	↘	↘	↘	↘	↘	↘
<b>Forest stand characteristics</b>						
Distance to forest edge (decrease)	↘	↘	↘	↘	↘	↘
Species heterogeneity (increase)	↘	↘	↘	↘	↘	↘
Forest type (more coniferous forest)	↘	↘	↘	↘	↘	↘

Fig. 3. Linear models for environmental variables and positive or negative NDWI changes of <math>\geq 10\%</math> for 2017–2018 (resistance to the 2018 drought event), 2018–2019 (recovery), and 2017–2019 (resilience).

#### Discussion

**Climate drivers:**

- Most linear fits between climatic variables and strong forest responses (negative and positive) were non-significant.
- The coarse spatial resolution of the weather data probably suppressed important local variation in highly varying topography.
- Higher temperatures correlated positively with strong positive NDWI changes which were prominent in alpine regions. In these regions the positive effects of higher temperatures meant no energy limitation, a longer growing season, and improved growing conditions and seem to have outweighed the negative effects of reduced precipitation.

**Topographic modifiers:**

- Higher elevations recorded positive rather than negative forest drought responses.
- Increased drought resistance on steeper slopes which are more used to reduced water availability due to faster run off.
- The low resistance on southern facing slopes which are generally better adapted to warmer and drier conditions indicates that there is a tipping point where previous adaptation is not enough anymore.
- Topographic exposition (e.g. on a ridge) also means stronger exposition to increased winds and radiation compared to sheltered and shaded downhill positions. Though the resistance was non-significant, both recovery and resilience were reduced at more exposed locations, where there is also reduced buffering of soil water availability.

**Forest stand characteristics:**

- Forest edges were clearly more exposed to drought damage as reflected in their low resistance. Which stems from less favourable micro-climatic conditions causing higher evaporation and even accelerate soil water stress.
- Forest locations with higher species heterogeneity where niche partitioning reduces interspecific competition also showed higher resistance.
- Whereas the linear model fit between drought resistance and forest composition was non-significant, forest composition was the most important driver of resilience in our study. Coniferous trees were more damaged by the drought. They generally have shallower rooting depths limiting them in reaching water in deeper soil layers. Additionally, post-drought bark beetle outbreaks in debilitated forests only affect conifers.


#### Conclusion

The contributions of the environmental drivers to forest drought responses were largely independent of each other. After correcting for differences between regions (used as random-effects term), the environmental drivers studied explained a large proportion of variance in forest drought response, reducing unexplained variation to only around 20%. This could be further reduced when taking other environmental drivers such as soil type or species-specific drought vulnerability into account.

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\*Eawag, Swiss Federal Institute of Aquatic Science and Technology

Sturm, J., Santos, M. J., Schmid, B., & Damm, A. (2022). Satellite data reveal differential responses of Swiss forests to unprecedented 2018 drought. *Global Change Biology*, 28(9), 2956–2978.

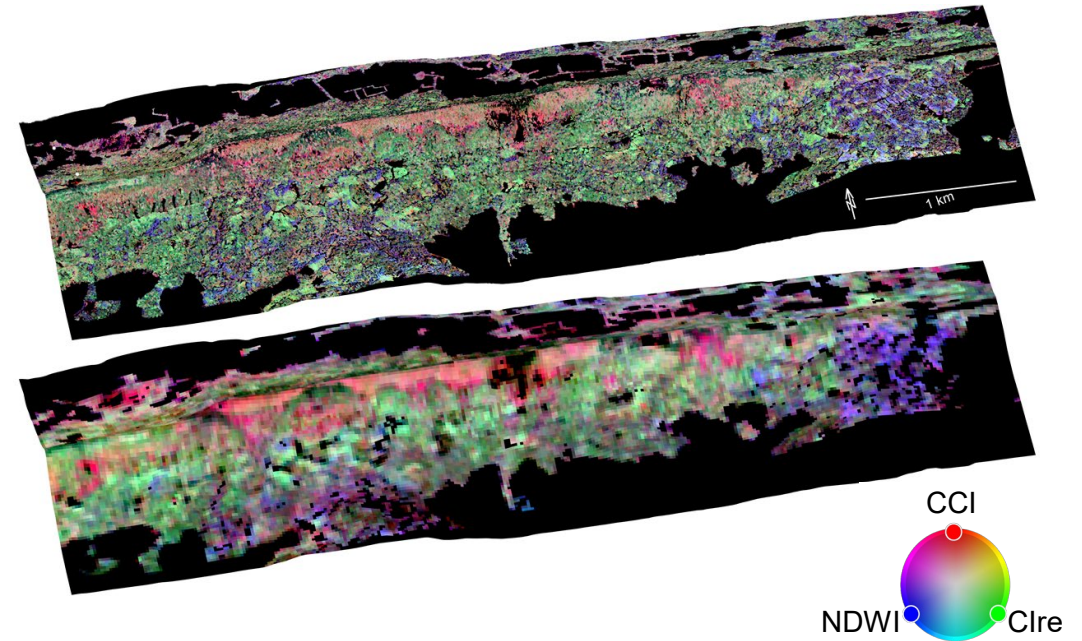
This study was supported by the University of Zurich Research Priority Program on Global Change and Biodiversity (URPP-GCB).





# Functional diversity at landscape scale using Sentinel-2 imagery

- Observing functional diversity continuously in time and space using satellite imagery
- Functional diversity metrics depend on the size and number of pixels
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- Importance of spatial and spectral resolution when scaling diversity assessments to landscape scales
- Promising applications at landscape scales



**Thank you for  
your attention! 😊**



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